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UNITED STATES EXPERIENCE WITH ALTERNATIVE SEWERS

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16. ABSTRACT

The history of development of alternative sewers in the United States is discussed along with their basic design features and extent of their use at the present time. Guidance is provided in the form of field experience and rational projections for engineers to estimate the capital and operation and maintenance costs of alternative sewers. Logic is also provided on the best use of these technologies in pure or combined form for a variety of environmental conditions.

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INTRODUCTION

The disposal of human wastes in an environmentally acceptable manner has been a problem throughout history. Historical evidence of early man's struggle to overcome this problem has been recorded and related elsewhere. Little progress has been recorded between the pre-Christian solutions described in the literature and the mid-19th century rebirth of municipal sewage in Europe and the United States, a development that has continued to the present. Between 1857, when the first large American system was installed in Brooklyn, N.Y. and 1905, about 28 million Americans were "sewered." By 1940 more than half of the total U.S. population was served by sewers, and the figure now stands at about 74 percent.

A review of nearly 300 facility plans for rural communities in the United States in the mid-1970's showed that the cost of conventional gravity sewers averaged more than $30 per month per house for population densities less than 4 persons per acre (1.6 p/hectare) and more than $20 per month for population densities less than 8 persons per acre (3.2 p/hectare). Monthly household charges much above $20 are considered excessive in rural areas where median incomes are generally significantly lower than in urban areas. Because most onsite wastewater disposal systems would cost each house significantly less than $20 monthly, the onsite approach has been generally used in these areas. Difficulties have arisen in areas where conventional onsite systems have failed because of unfavorable soil conditions. Until recently, the solution to failed onsite systems was almost invariably a recommendation to install conventional sewers in the community. Implementation of this recommendation depended on the financial status of the community, availability of Federal grants, and public attitude. Unfortunately, the cost of conventional sewers is extremely high for most small communities. In fact, it is not uncommon to see engineering estimates in excess of $10,000 per home. Also, the cost of the conventional collection system generally represents more than 80 percent of the total system capital cost in rural areas. The inverse relationship between cost and population density is primarily explained by the greater length of sewer per contributor and greater problems with grade resulting in more lift stations or excessively deep sewers.

Unfortunately, many situations have come about in recent years that cannot be solved by either of the traditional options, and the results of attempts to apply either technology in these situations have been unsatisfactory to all involved. For example, building moratoriums have been imposed that prevent the development of highly desirable land parcels; conventional sewers have been installed at tremendous cost to the homeowners serviced; and septic tank-soil absorption systems (ST-SASs) have been constructed that cannot function properly, therefore contaminating the very environment that made the site so attractive originally.

The technological alternatives developed over the past two decades to eliminate the above dilemma vary from near-elimination of water-carriage for

human wastes to alternative onsite and collection technologies which overcome site constraints and/or significantly reduce the cost of environmental sanitation.

Alternative Sewer Technologies

The three basic types of alternative collection systems discussed herein are pressure, vacuum and small-diameter gravity (SDG) sewers. Their descriptions and histories of use are provided below. All three have been designated as "Alternative Technologies" under the provisions of the Clean Water Act of 1977, and are eligible for 75% rather than 55% Federal funding.

Pressure Sewers

Although sewage pumping has been practiced for many years in municipal systems in the form of lift stations and force mains to avoid excessive depths of cut, and in many individual homes in the form of ejector or sump pumps, the wholesale use of small-diameter pressure collection systems did not emerge until the latter part of the 1960's.

The advantages of pressure sewers are primarily related to installation costs and inherent system characteristics. Because these systems use small-diameter plastic pipes buried just below the frost penetration depth, their installation costs can be quite low compared to conventional gravity systems in low-density areas. Other site conditions that enhance this cost differential include hilly terrain, poor load-bearing soils, rock outcropping, and high water tables. Because pressure sewers are sealed conduits, there should be no opportunity for infiltration, and treatment plants can be designed to handle only the domestic sewage generated in the homes serviced.

The two major types of pressure sewer systems are the grinder-pump (GP) system and the septic tank effluent pump (STEP) system. The major differences between the pressure systems are in the onsite equipment and layout. Some significant differences also exist in the pressure main design methods and in the systems required to treat the collected wastewater to an environmentally acceptable level. Neither pressure sewer system requires any modification of household plumbing, although neither precludes it if such modifications are deemed desirable. Both systems also have the potential for severe corrosion and odor problems owing to high sulfide concentrations if improper engineering design and materials of construction are employed. Sulfide concentrations have been infrequently measured, but fall in a range between 1 and 14 mg/L, with GP's showing an increasing trend from origin to terminus and STEP's showing a stable to decreasing trend in this direction.[1]

In 1977 it was determined that nearly 80 pressure sewer systems were either in operation or design/construction in the U.S. Of the 59 operating systems identified at that time 83 percent were GP systems and 17 percent were STEP systems[2]. The preponderance of GP systems was likely related to the early Federal demonstration projects which were all based on the GP concept. STEP systems were initially funded by private entities and the Farmers Home Administration of the Department of Agriculture, but were later included in the EPA demonstration program.

Both variations in pressure sewer technology were first summarized in a useful format in 1977.[2] Review of EPA Construction Grant projects involving Innovative/Alternative (I/A) Technologies up to 1983 reveals that about 2/3

of the 146 small community wastewater collection systems funded under this program are pressure sewers; and by 1986 58% of the 384 I/A alternative sewers were of this type. An August 1985 review of EPA-funded alternative sewer projects in the states of Minnesota, Wisconsin, Michigan, Illinois, Indiana and Ohio indicated that more than eighty (80) such systems had been approved, 23 of which were either under construction or in operation.[3] The 23 included 8 GP systems and 6 STEP systems. Construction costs per connection normalized to the first quarter of 1985, varied widely for all pressure sewers with fewer than 75 connections. Above this level the GP installations varied from $5,000 (U.S.) to $6,400 per connection, while the range for STEP installations was from $4,300 to $5,200 per connection.

Small-Diameter Gravity Sewers

Small-diameter gravity (SDG) sewers have also been called "effluent drains", a term employed by the Australians who have employed the technology for almost 25 years. Development and use of SDG sewers in both Australia and the U.S. was prompted by the prohibitive cost of conventional sewers for rural community wastewater conveyance.

In essence, there are two types of SDG sewers, those with relatively constant grade and those with variable grade. Both types utilize small-diameter plastic pipes and carry septic tank effluent. The septic tanks are required to remove grease, grit and other heavy solids to minimize the need for maintaining scouring velocities in the sewer.

The advantages of SDG sewers over conventional gravity sewers include lower capital cost due to reduced pipe and installation costs, cleanouts in place of manholes, reduced lift station sizes due to flow peak attenuation by septic tanks, reduced infiltration and inflow (I/I), and potential reduction in treatment costs due to septic tank pretreatment. Disadvantages include the continued need to maintain and pump septic tanks and the special design problems relative to odor and corrosion inherent with septic tank effluent, although a recent study indicates that concentrations of sulfide in these sewers are significantly lower than in STEP systems which also convey septic tank effluent.[1] It appears that venting these sewers to the atmosphere permits a reduction in normal sulfide concentrations of septic tank effluent.

The first major SDG sewer in the U.S. was constructed in 1977 in Westboro, Wisconsin. This system has over 85 connections, serving about 200 people. The system was designed in accordance with the guidelines of the South Australia Department of Public Health, with certain modifications required by the Wisconsin Department of Natural Resources. These modifications required manholes at the upstream end of each line, at all junctions, and at intervals of not more than 600 ft(180 m).[3]

A much smaller system in Mt. Andrew, Alabama, was constructed in 1975 with a variable grade approach and no manholes or cleanouts. It has provided several years of maintenance-free performance, with the exception of septic tank pumping. The USDA Farmers Home Administration staff employed their own set of design criteria. These criteria are based on the use of a special two-compartment septic or interceptor tank which is designed to further minimize surge conditions at peak flows. In this manner, the system pipe size was minimized.[4]

Experience has indicated that manholes should be avoided, except at major junctions and inspection points, as they represent a potential source of additional water, solids and odor. Non-corrosive materials must be incorporated in the design.

After the two initial U.S. installations and the heightening of interest in the need to provide low-cost sanitation in small communities in the late 1970's, the SDG concept has rapidly developed as an effective pollution abatement concept. As of August, 1982, approximately 25 percent of the small community alternative sewer projects funded under the I/A setaside of the EPA Construction Grants Program have utilized SDG systems (as of 1986, 38%). The 1985 review of midwestern systems indicated that 9 of 23 systems in the construction/operation stage were SDG systems. Also, in non-EPA projects the SDG sewer has found numerous applications due to its low capital cost and non-mechanical nature, which makes it attractive for small communities which must provide the necessary system O/M without assistance.

A review of 10 operating U.S. SDG systems revealed that construction cost savings varied from 0 to 50 percent compared to conventional systems.[4] Construction (bid) costs averaged $4,335 per connection normalized to the second quarter of 1982. The previously described midwestern review showed a variation from $1,700 to $6,200 per connection, normalized to the first quarter of 1985.[3]

Vacuum Sewers

The vacuum sewer concept was first patented in the U.S. in 1888 by Adrian Le Marquand. Vacuum systems depend on a central vacuum source constantly maintaining 15 to 25 inches of mercury (380 to 625 mm Hg) on small-diameter collection mains. A gravity vacuum interface valve separates atmospheric pressure from the vacuum in the mains. The valve can be either in the home sanitary sewer service line or in a vacuum toilet. When the interface valve opens, a volume of sewage enters the main, followed by a volume of atmospheric air. After a preset interval, the valve closes. The packet of liquid, called a slug, is propelled into the main at a high velocity by the differential pressure of vacuum in the main and the higher atmospheric pressure air behind the slug. After a short distance, the slug is transformed into foam and the momentum is imparted from the air to the sewage through shear forces. Eventually friction slows the sewage velocity, and it then flows to the lowest local elevation by gravity.[5] When the next upstream interface valve operates, identical actions occur, with that slug breaking down and air rushing across the second slug. That air then impacts downstream liquid, lifts it and forces it further down the system. After a number of operations, the first slug arrives at the central vacuum source. When sufficient liquid volume accumulates in the collection tank at the central vacuum source, a transfer device, such as a sewage pump, delivers the accumulated sewage to a treatment plant.

Although several types of vacuum equipment and designs are available, they all operate on the general principles described above. The first commercial application of vacuum sewers was in Sweden in 1960.[6] These systems employed vacuum toilets, but subsequent developments have tended to utilize normal or gravity-based flow reduction household plumbing fixtures with subsequent transfer of the combined wastewater to the vacuum sewer main through a single interface valve. This form of vacuum sewerage offers reduced power consumption, since the magnitude of vacuum required to operate vacuum toilets is significant. By 1977 there were seven U.S. vacuum systems in operation. A review of I/A small community projects in late 1982 revealed that 7 of 146 were vacuum systems (in 1986, only 12 of 356). At least 20 systems were in operation or under construction in the U.S. as of the summer of 1984.

The advantages of vacuum sewers over conventional sewers are similar to those previously stated for pressure and SDG sewers, reduced capital costs due to small plastic pipe use and reduced depth of installation, especially where gravity systems require multiple lift stations. The unique advantages of vacuum systems are the substantial dissolved oxygen content of the wastewater and the centralized power utilization at the vacuum station. Disadvantages compared to other alternatives include a higher energy requirement per unit volume of wastewater transported, greater potential for infiltration, need for more exact grade alignment during installation, and a limitation on allowable system lift.

Practical Applications

All of the alternative systems can be advantageously utilized in certain rural community applications. Each has certain unique characteristics which may dictate its use under a certain set of circumstances which requires that each potential application be analyzed for the most cost-effective system in that specific set of local conditions. The following discussion attempts to generalize the relative merits of each collection alternative with regard to certain physical, administrative and technological constraints which may exist at a given site. Because of the general nature of such an analysis and the probability of contradictory constraints at real project sites, these generalized statements should be regarded only as assistance to the engineer in preliminary assessment of potential collection system choices.

Topography

In rural areas with hilly terrain, the already high cost of conventional sewers are made even more acute by multiple lift stations. Although less expensive, the cost of SDG systems can be greatly increased by this same condition. If the required lifts are relatively small, vacuum sewers may be feasible, but not for major lifts. Both types of pressure sewers are quite amenable to uphill runs, but incur cost increases in certain undulating terrains. Probably the most cost-effective solution would be a mixed one employing two compatible types of collection, e.g., SDG and STEP.

Geology/Hydrology

Conventional sewers incur severe increases in costs where rocky or high groundwater conditions are encountered. Due to their reduced depth requirements, pressure and vacuum sewers become even more cost-effective under these conditions. SDG sewers may have similar advantages, since they can to a large degree follow natural contours (even to the extent of having permanently flooded sections) but they generally cannot completely avoid some of the inherent problems of gravity sewers.

Climate

In warmer climates conventional sewers have often developed sulfide problems. Because of their inherent use of septic tanks STEP and SDG systems already have a significant sulfide problem, even though the latter does demonstrate reduced sulfide concentrations from original (septic tank) levels. Larger GP systems have demonstrated similar problems, especially during warm

periods. Vacuum sewers alone would appear to be best suited for preventing sulfide problems due to the inherent turbulence of the flow. In cold climates, insulated plastic pipe pressure sewers have been demonstrated to successfully overcome the need for greater pipe depth due to increase frost penetration for pressure sewers. This technique should be equally effective for vacuum sewers, but it has not yet been demonstrated. SDG systems would be less likely to freeze than conventional gravity systems due to the minimization of manholes, and no freezing problems have been reported by operating systems.

Population Density and Growth

Conventional sewers are advantageous in urban areas with greater population densities. Due to their high cost per unit length and the greater length required per connection in rural areas, they are generally not cost-effective. Vacuum sewers are also sensitive to population density due to limiting line lengths, and have an optiimum cost-effectiveness when design populations are relatively concentrated. SDG systems, due to their reduced minimum velocity requirements, can handle a wide divergence between initial and ultimate design populations. Pressure sewers depend on the type of design chosen. GP systems require minimum scouring velocities to be reached daily. Therefore, a low ratio of initial to final design population will likely require periodic flushing of the main. STEP systems, like SDG sewers, carry septic tank effluent and are not constrained by lower initial flows. Flows in excess of STEP system nominal design capacity can be accommodated by use of timing controls which provide pumping of wastewater during otherwise low-flow periods of the diurnal cycle.

System Management

The management needs for conventional sewers are well documented. Given the simple nature of SDG systems, the management needs are negligible. Pressure and vacuum sewers are mechanical in nature and have a requirement for reasonably skilled O/M staffs. Although their mainline requirements may be equal to or less than conventional sewers, their on-lot facilities and, in the case of vacuum, central station facilities require trained O/M personnel with appropriate support equipment and ancillary facilities. SDG and STEP systems do require regular pumping of pretreatment tanks. All systems must be designed for flushing, but most have not implemented programs.

Power

Conventional gravity and SDG systems may not require any power for operation if appropriate topography exists. The central vacuum stations of a vacuum sewer are generally supplied with standby power generation. Pressure sewers, however, are subject to the reliability of power supplies and must be designed in accordance with power outage records for the service area. STEP systems generally accommodate lengthy outages due to inherent excess capacity in the septic tanks. GP systems may require some form of emergency overflow in areas where outages exceed their limited capacity for storage. Power requirements for the three mechanical systems are lowest for STEP, intermediate for GP, and highest for vacuum.

Habitation

Most comparisons of systems are based on full-time habitation. It is rare that an entire community is seasonal. Most SDG and STEP systems would be relatively unaffected by such conditions, as no minimum velocity is required. Conventional and GP systems, owing to their requirement for minimum velocities, could be significantly affected and require some form of flushing during the off-season. STEP, GP and vacuum systems could be severely limited by long periods of disuse of on-lot facilities if the climate is very cold, unless special insulation or O/M procedures are employed to counteract the problem.

Termination Facilities

Discharge of the alternative sewer at treatment facilities is discussed in the next paragraph. Discharge into an existing conventional sewer can present several problems for all alternatives except vacuum sewers. When large GP systems and STEP and SDG sewers terminate into an existing sewer, two potential problems exist. First, is the problem of odors, which can be effectively controlled through smooth transition hydraulics, such as tangential discharge below the liquid level in the manhole. The second and far more serious problem is corrosion. If the receiving manhole and sewer are constructed of concrete, destructive corrosion problems can result if the sulfide-laden sewage constitutes a significant portion of the total sewage flow. Although exact criteria for the threshold flow ratio and the downstream reach of this corrosion is not yet available, there appears to be a need to evaluate the cost trade-offs between a transition (sulfide oxidation) facility and a corrosion-resistant modification to the existing sewer and manholes for a yet unspecified distance downstream of the connection.

Treatability

Septic tank effluent which is transported by SDG and STEP systems is quite amenable to aerobic biological treatment. In fact, due to the reduced I/I of both systems and the minimal concentration of grease, grit and settleable solids in this wastewater, reduced hydraulic capacity of the treatment facility is feasible, along with elimination of preliminary and primary treatment systems. Special materials of construction and immediate oxygen demand requirements must be considered during the design of treatment facilities for these wastewaters. GP wastewater is stronger than normal wastewater, owing to the elimination of I/I. Although it is amenable to normal secondary treatment systems, the total volume of sludge generated should be greater than the conventional case, which may offset potential savings in reduced hydraulic loading and preliminary treatment requirements. Vacuum sewers produce a wastewater whose strength lies somewhere between normal and GP wastewater, with a generally high dissolved oxygen due to turbulence inherent in the collection system. This wastewater is quite similar to normal wastewater with regard to treatment. The effects of this wastewater on primary treatment efficiency are not well-documented.

Perspective

In rural areas conventional gravity sewers are rarely cost-effective. Each of the alternative sewer systems described herein have characteristics which might make them singly or in combination the most cost-effective solution in a given set of circumstances. For example, in very small existing communities with gentle downhill slopes and minimal O/M capability, an SDG system should be strongly considered. Similarly, in small existing communities where the optimum location of treatment and disposal facilities is at a higher elevation than the community, a STEP sytem should be seriously evaluated. Also, in small fringe areas which are at low elevation in relation to a larger conventional sewer, a GP system could possibly be the optimum choice. In relatively flat areas with reasonably dense suburban development with access to a large existing collection sewer, vacuum sewers should be evaluated as a potential optimum solution.

Combinations of alternative sewers are also feasible as the most cost-effective solution. SDG and STEP systems have been combined with excellent results. Combinations of GP and conventional gravity and of vacuum and conventional systems are also common. The engineer must consider not only each alternative sewer, but combinations which utilize the inherent advantages of compatible systems.

Performance, Operation and Maintenance

Many state regulators and engineers have accepted the capital cost advantages of alternative sewers in smaller communities, but many continue to doubt their performance reliability and believe their operation and maintenance (O/M) requirements are high. Recently data on both these factors have shed some additional light on these factors.

One method of measuring reliability is to measure the mean time between service calls (MTBSC) for various components of a system. This parameter, expressed in units of time (usually years), provides a measure of average service life of the designated component before the management authority must provide repair service. For example, if there were 400 pumps in a pressure sewer system and each year 100 pumps required service, the MTBSC of the pumps would be 4 years. The routine O/M designed to increase MTBSC for any system is commonly referred to as preventive maintenance (PM). Preventive maintenance consists of regularly scheduled inspection and maintenance tasks which prevent or forestall unnecessary emergency repair requirements. The fact that some smaller alternative sewer systems do not incorporate a PM program is due in part to the fact that the tradeoff between MTBSC times and PM programs have not been well-quantified for those systems.

Pressure Sewers

There are a number of factors involved in an appropriate preventive maintenance program. Among these are supervision and inspection of onsite installations, periodic inspection of mainline and onsite facilities, assistance to excavators on line locations, flushing of mains, exercising valves, cleaning pressurization sumps and other tasks specific to the equipment installed. Administrative tasks including payroll, clerical, budget and billing services are part of the overall management function, but are excluded from the preventive maintenance program as defined here.

An additional factor which must be included in any analysis of O/M is that the first year of operation reflects a greater need for service calls than subsequent years due to unforeseen design and construction problems. Therefore, MTBSC analyses may reflect this phenomenon. Also most manufacturers provide a one-year warranty on their equipment. Also, many of the data related herein are from early installations which represented pioneering designs of equipment and systems. Subsequent technology advancement will usually improve the reliability data for any of the technologies discussed.

There are two categories of GPs: semi-positive displacement (progressing cavity) and centrifugal. Both utilize cutters prior to the pumping step. The major mode of failure with the former is failure of the flexible boot (stator) which surrounds the rotor. With the latter type most problems have been traced to air binding and locking. MTBSC data for these GP units have been found to vary between 2 and 5 years.[5]

STEP system onsite installations may vary more than their GP counterparts because the latter are generally sold as a complete package, while the former may sometimes be "engineered" from several vendor sources. In some cases this engineered approach has resulted in increased maintenance requirements due to design oversights or errors or improper construction practices.

MTBSC information for several STEP installations is shown in Table 1.

TABLE 1. MTBSC DATA FOR STEP ONSITE FACILITIES

Location (yr of operation)	No. of Units	MTBSC (yr)
Port St. Lucie, FL (5)	87	3.6
Port Charlotte, FL		
Sec. 18 (8)	29	6.3
Sec. 54 (6)	33	7.7
Manila, CA (2)	254	3.5
Glide, OR (1)	328	6.2

Preventive maintenance plays an unquantified positive role in reducing system difficulties. Originally, some Florida systems scheduled preventive maintenance calls every three years. These are now performed annually. Reduced service calls are attributed, in part, to more frequent preventive maintenance. An Idaho system also schedules one preventive maintenance call per year, at which time the pumps are inspected and chambers are hosed to remove buildup of oils, greases and scale. At Glide, Oregon, the annual inspection involves visual checks, pump vault washdown when required, and septic tank sludge and scum accumulation measurements. At Manila, California, annual O/M manpower requirements are inordinately high because of the arbitrary plan for quarterly maintenance. No other system utilizes a preventive maintenance schedule of less than one year.

Mainline O/M is similar for both GP and STEP systems even though the hydraulic design approach to each is quite different. Neither requires manholes, while both require cleanouts at termination points and at intermediate locations where pipe junctions occur. Mainline shutoff valves are suggested at 600 ft. and 1000 ft. intervals for high and low density service populations by Florida Guidelines.[6] Air release valves are generally required near high points in the system where the downstream slope exceeds 10% and the length of run is substantial.

Bowne and Ball[7] indicate that the preventive maintenance (PM) program for Glide includes annual exercising of shutoff valves and periodic (unspecified intervals) inspection of air release valves, with flushing as required. Flushing of mains has not been necessary for any STEP systems and is generally not practiced for GP systems, except in developments where early hydraulic loads are but a fraction of the system design loading. Flushing programs are maintained at the Horseshoe Bay and Point Venture, Texas GP systems. The Apple Valley, Ohio system PM program incorporates annual exercising of shutoff valves and flow reversal in looped lines. One manufacturer of a GP system has suggested periodic mainline pressure measurement to determine if and when flushing might be necessary.

Actual mainline emergency maintenance has been extremely rare and usually associated with excavation damage to the pipe. Freezing problems resulted in a line break at Weatherby Lake, Missouri, and 8 instances of frozen mainlines were reported during a nearly 4-year period at Apple Valley. Freezing problems are avoidable with proper design, as demonstrated by systems in Canada which have operated successfully without these problems. The early Grandview Lake, Indiana system suffered pipeline damage by excavation earthslides and improper construction. Other pressure sewer system O/M problems have resulted from odors and corrosion.

All pressure sewer systems require designer attention to materials of construction which are exposed to the wastewater or atmosphere of the pressure sewer system. With such proper design consideration, unnecessary O/M problems can be avoided.

Odor problems have been documented at several locations. The most commonly observed location for odor problems is at lift stations. Several novel methods have been used to overcome the odor problems. For example, odors from the lift stations at Kalispell, ID and Glide, OR are vented to drainfields for soil scrubbing. At some smaller systems when odors are found, the remedy involves resetting the level controllers or timers on the pumps for more frequent pumping events. Weatherby Lake adds hydrogen peroxide (0.06 m^3/day (15 gal/day) of 35% hydrogen peroxide) at three lift stations for odor control during warmer periods.

Odor abatement systems where unfavorable odors occur can represent an O/M requirement in themselves, depending on the abatement system chosen, and must be included in the overall O/M plan for the system. For example, the soil filter approach may require periodic wetting, while warm weather peroxide addition requires the cost of chemicals and labor to makeup chemicals and maintain the feeding system.

Small Diameter Gravity Sewers

The U.S. experience with small-diameter gravity (SDG) sewers is limited. The only O/M problems of significance on the Mt. Andrew, Alabama and Westboro, Wisconsin systems with 8 and 6 years, respectively of operating experience, has been the pumping of septic tanks. At Mt. Andrew some of the small tanks employed required pumping in a little more than one year. However, at Westboro the residential septic tanks are pumped at 3-year intervals, while tanks serving commercial establishments are pumped annually. Infiltration and inflow have been serious problems at 3 of the U.S. systems due apparently to inadequate on-lot facilities rather than mainline sources. Potential odor and corrosion problems are similar to pressure sewers and are controllable in similar ways.

The Australian experience with SDG sewers is quite significant compared with that in the U.S. In 1982, over 65 SDG systems were operating in South Australia with more than 500 miles (800 km) of SDG mainline. Early installations utilized vitrified clay piping which was found to suffer from root penetration and blockage. Since then the use of PVC pipe with solvent-welded joints has eliminated this problem.

Annual flushing is recommended by the South Australia Health Commission to prevent the accumulation of gas-producing solids. However, it has been noted that systems that were not flushed did not apparently suffer any major blockage problem.[8] Septic tank pumping has normally been scheduled for every 5 years. Addition of hydrated lime to freshly pumped septic tanks has also been practiced to reduce the occurrence of odors from house vents.

Mainline O/M costs can be considered similar to pressure sewers, however, the potential need for line flushing must be considered greater than for a STEP system until more experience is gained on the actual necessity for this O/M task. Of course, if lift stations are required, the mainline O/M costs will become quite significant.

Septic tank pumping requirements would be identical to those for STEP systems, since the need to avoid solids carryover is identical in each system.

Vacuum Sewers

Many of the observations noted under pressure sewers are applicable to vacuum sewers as well. The likelihood of higher maintenance requirements during the startup phase due to foreign materials entering the system during construction and connection phases is to be expected. Mainline repairs would also be similar for vacuum systems since the piping materials and shallow burial depths are basically the same.

There are three primary areas of potential maintenance with a vacuum sewer, i.e., the interfacing valves, the vacuum main and the vacuum station. Historically, the interfacing valves, particularly the controller mechanisms, have been the primary source of O/M service call demand. Manufacturer improvements in the controller have not been fully evaluated from an operational standpoint because of insufficient field data at this time.

In accordance with manufacturers, Eblen and Clark[9] recommended an annual inspection of valves, valve pits and wastewater sumps (to prevent increased service calls due to grease accumulation) in addition to inspection and cleaning of valve breathers, check valves and solenoids. The time requirement for this onsite preventive maintenance is regarded as minimal by manufacturers, but was estimated by Eblen and Clark to require 3 man hours per valve per year,

including the removal of accumulated grease. Based on minimal additional information, an estimate of one annual man hour per valve should be reasonable.

In the same manner as pressure sewers, vacuum sewer onsite component reliability may be expressed as mean time between service calls (MTBSC). MTBSC data on six systems vary from 1.5 to 10 years, with 2/3 less than 4.0 years.

The predominant U.S. vacuum sewer manufacturer recommends the removal and rebuilding of the valve every five to six years. Eblen and Clark[9] suggested a major valve repair might be called for every 5 years, requiring five man hours of labor. The present manager of the Country Squire Lakes, Indiana system has routinely been performing this function every four years. Although the manufacturer indicates that this effort involves only about $10 in parts, i.e., new seals, diaphragms, shaft seal and seat, the labor cost and man hours are not specified. It appears reasonable to assume that the travel, removal and shop time would require 5 man hours per repair.

In addition to the interfacing valves, the other major O/M problem relates to the vacuum station, e.g. oil levels, indicator lights and vacuum chart recorders. Daily inspection of the vacuum station is recommended.

Preventive maintenance (PM) for the vacuum station is estimated by Eblen and Clark[9] to require 50 man hours per year (twice per week). Few other data sources are specific to vacuum station PM, but Westmoreland, TN has had a malfunctioning alarm system causing the number of daily inspections to increase from one to five. Even at one-half hour per occurrence, a daily inspection should require about 180 man hours annually, while five would approach 900. Mathews, Virginia was reported to spend between 100 and 200 man hours per year on vacuum station operation/preventive maintenance, while the system at Foxcliff Estates in Indiana required 120 to 180 annual man hours. Based on the above information it is reasonable to assume that vacuum station operation and preventive maintenance should require approximately 200 man hours per year of O/M staff effort, not including major overhauls of equipment which would probably be performed on a contract basis.

Mainline O/M requirements should be quite similar to pressure sewers. Both are usually located just below the frost line, are generally of PVC fabrication, and are equally subject to damage by excavation. Therefore, in the absence of any mainline O/M information, the O/M requirements for mainlines can be estimated to be about 0.1 man hour per year per user for routine O/M plus a reasonable manpower requirement for each mainline emergency. As with pressure sewers, the number of anticipated incidents of mainline damage will be related to the growth factor of the service area and the capability of the management entity to provide assistance to prospective excavators.

Cost Comparisons

As noted earlier the cost of alternative sewers is extremely site specific. The local conditions will determine the most cost-effective alternative sewer for a given community. In order to accomplish some form of generic comparison Kreissl, et al,[10] assumed a community size of 500 people (3.5 persons/dwelling) and no topographical or geological constraints to any of the sewering alternatives and found the capital costs of all 3 major alternative sewers to be within 10% of each other and about 30% less than conventional sewers. Actually savings in capital cost have been as high as

90 percent in some instances for pressure sewers because of their ability to serve difficult topographical situations with minimal increase in the unconstrained costs.

Operation and maintenance (O/M) costs are of major concern to the community primarily because they represent a continuing demand over the life of the collection system, and also because they contribute to the present worth of the alternatives in the cost-effective analysis to determine the optimum system. Annual O/M charges for 8 pressure sewer systems vary from $60 to $145 per year per household served. It is impossible to accurately compare these charges since many include treatment and administrative costs (some may even include debt services).

In terms of recommended charges for STEP systems and GP systems, it is suggested that annual user charges, excluding debt service and administrative costs, should fall between $50 and $100, unless unusual and site specific circumstances dictate otherwise.

If septic tank pumping is planned at 3-year intervals, for example, and costs $60, the annual cost of this O/M task is $20. If 20% of a 100-home SDG system requires pumping due to elevation problems, appropriate preventive maintenance, power and apportioned emergency service calls would be basically the same as a STEP system or 1/5 x $50 to $100, or $10 to $20 per user annually. If that same system required a lift station instead of the 20% STEP units, the cost per user could be even higher. Mainline preventive maintenance, assuming no flushing, would be on the order of one dollar per year per user.

It is clear from the above that the O/M cost of a pure SDG sewer is quite low, as little as $20 per year per user. However, the need for lift stations and other specialized mechanical adjuncts can quickly add significantly to the cost of O/M. The actual O/M cost will be reflective of the local conditions and final systems design.

Total O/M for a vacuum sewer system must include power, preventive and emergency labor requirements, major (contract) repairs, spare parts and supplies. If the earlier determined preventive maintenance levels of 200 man hours per year per vacuum station and one man hour per year per vacuum valve are assumed along with a reasonable MTBSC for the valves and the vacuum pumping station equipment, the only remaining O/M costs are for power and mainline requuirements.

Wastewater volume per unit of power has been measured at several locations and reported to vary from 0.04 to 1.6 m^3/kWh. Eblen and Clark[9] measured the total demand at 1.36 kWh/user/day. Data from Westmoreland, Tennesee indicate about 3¢/day/user and from Fairmount, Maryland about 6¢/day/user. Plainville, Indiana power costs indicate that 4¢/day/user is being consumed by the vacuum system. Foxcliff Estates, Indiana costs were found to be between 11 and 12¢/day/user, while Country Squire Lakes, Indiana requires about 3¢/day/user. Based on the above data, power requirements can reasonably be estimated at 1 to 2 kWh per day per user at the local electric rate. Mainline O/M costs would be similar to pressure and SDG systems, or about two dollars per user served per year.

Comparing alternative sewers to conventional gravity sewers, an internal USEPA review of 132 small conventional sewers indicated that for a conventional gravity sewer servicing a community of 500 with an average of 3.5 persons per home, the average annual O/M cost was $4,800 or about $33.00 per user. This would be slightly in excess of the O/M cost of SDG system, without lift stations. Thus, on the basis of O/M costs for sewers under ideal topographic

conditions, pressure and vacuum sewers would generally be more costly. However, since the O/M cost of a conventional sewer is normally quite small compared to amortized initial cost, alternative sewers are clearly more cost-effective in rural areas.

There are several factors which can affect the comparative economics between conventional and alternative sewers and between the different alternative sewers. These factors include proximity of serviced dwellings and new vs old development, in addition to all of the factors cited previously.

The proximity of dwellings in the service area will, if they are sufficiently close, allow for combination of onlot facilities. With pressure sewers the use of one pressurization unit for two homes could reduce initial costs and combinations of three homes on a single unit have been successfully demonstrated. Similarly, with vacuum systems combinations of as many as 8 homes per valve have been successfully used. In both of the above examples, concomitant O/M cost reductions would also be expected, though not in direct proportion to initial costs.

Where existing community wastewater facilities are being modified due to failure of onsite wastewater disposal systems, continued use of existing septic tanks could significantly reduce initial costs of STEP and SDG alternatives. Further reduction could be realized at a terminal treatment facility for both of these alternative sewers by taking advantage of pretreatment by septic tanks and the absence of or reduced infiltration in designing the treatment system.

SUMMARY

Pressure, vacuum and small-diameter gravity sewers have become a valuable engineering alternative to conventional sewers in the United States over the past fifteen years. Although there remains a need to fully quantify long-term operation, maintenance and performance characteristics, the apparent economic advantages of these systems are sufficient to have caused widespread adoption in rural communities.

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